International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-4, Issue-3, March 2017

VAr Compensation Based Stability Enhancement Of Wind Turbine Using STATCOM

P. Malathy, J.Lakshmi Priya

***Abstract*— Maintenance of power system stability becomes vital during disturbances like faults, contingency etc. This work deals with a novel priority oriented optimal reactive power compensation of Doubly-Fed Induction Generator (DFIG) based wind turbine using Static Synchronous Compensator (STATCOM). A multi-objective problem will be formulated to maintain voltage within its tolerance levels using Voltage Severity Index (VSI) and to mitigate low frequency oscillations by using Transient Power Severity Index (TPSI) during post-fault conditions. An optimal solution to this proposed problem will be obtained using Fuzzy Logic. In order to justify the proposed methodology it is simulated and tested using 2 MW DFIG with MATLAB- Simulink.**

***Index Terms*— stability indices; wind turbine; reactive power; fault; fuzzy logic; STATCOM.**

I. INTRODUCTION

An optimal reactive power and voltage control strategy of DFIG based wind turbine using Particle Swarm Optimization (PSO) is discussed in [1]. STATCOM has been used in a wind farm associated with DFIG for real time applications [3]. In [4] application of various FACTS controller models are validated for the real and reactive power coordination problems related to power system studies. An adaptive neural network configuration has been implemented [5] to control reactive power in a grid connected wind farm. Bacterial Foraging Technique (BFT) [7] has been used to maintain a constant power output in a DFIG based wind turbine and batteries. Genetic Algorithm has been applied to mitigate voltage sag, swell problems [8] in a grid connected DFI wind generators. A modified Differential Evolution (DE) algorithm has been used to design an optimal electric network for an offshore wind farm [9].Simulated Annealing technique (SA) has been used [10] for the optimal maintenance of constant voltage and power output in a DFIG based wind turbine. Real time transient stability analysis of a fixed speed wind farm is done using STATCOM [11]. In order to solve the low voltage problems in a grid connected DFI wind generators Genetic Algorithm (GA) has been applied [12]. A multi-objective problem using decomposition based evolutionary algorithm has been used to analyze the voltage stability [13].

This work presents, a priority oriented optimal VAr compensation of DFIG based wind turbine using STATCOM. A multi-objective problem is formulated to maintain voltage within its rated limits using VSI and to mitigate low frequency oscillations by using TPSI during three phase fault conditions.

The solution for the proposed problem is optimized using Fuzzy Logic. In order to justify the proposed methodology it is modeled in a 12 bus power system with a 2 MW DFIG using MATLAB- Simulink. The system is then tested by simulating a three phase fault. The graphical results of the case study are analyzed and presented.

P. Malathy, Department of Electrical and Electronics Engineering, PSNA College of Engineering and Technology , Dindigul – 624 622, India
J.Lakshmi Priya, PG Scholor, Department of Electrical and Electronics Engineering, PSNA College of Engineering and Technology,Dindigul, India

II. METHODOLOGY

A. *Snyopsis of the Proposed work*

The main objective of this study is to formulate a multi-objective problem for modeling a optimal reactive power controller. Transient stability of the system under consideration is improved by reducing the voltage deviations at the Wind turbine. Fig. 1, shows the general block diagram of the proposed model.

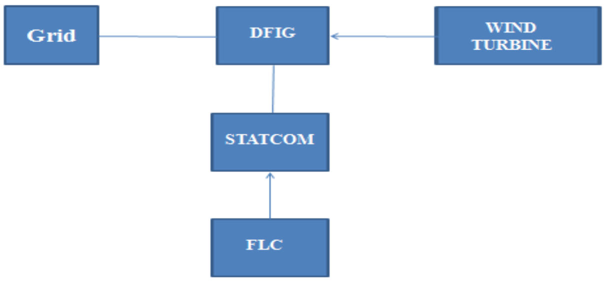

Fig. 1 Block diagram of the proposed control for stability improvement

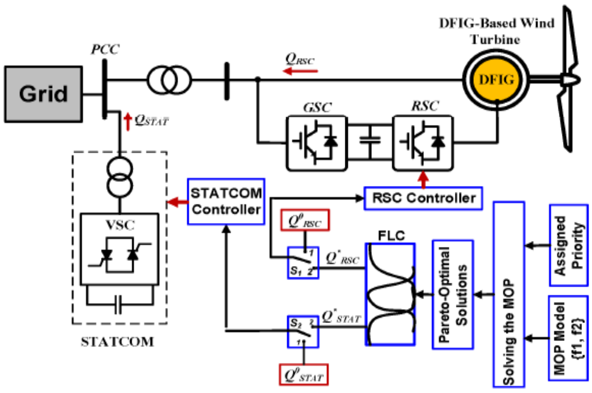

Fig. 2. Diagram of the proposed control [15]

Fig. 2, shows the detailed block diagram of the proposed model. Among various types of FACTS controllers STATCOM is chosen to regualte voltage through the reactive power compensation because of its superior dynamic voltage control capability.

The uniqueness of the proposed work is, it has two objectives. One of the objective is to minimize the voltage deviation at the Point of Common Coupling (PCC) in the system even during fault. The next objective is to minimze the TPSI to improve the transient stability by mitigating the oscillations after clearing the fault or during post fault conditions. The DFIG based wind turbine is connected to the

grid. It has been controlled by STATCOM using Fuzzy Logic Controller (FLC). The FLC is tuned offline, by a fuzzy model and a set of fuzzy rules as shown in Table I.

TABLE I. FUZZY RULES

Rule No.	Fuzzy Input		Fuzzy Output	
	Tf_1- Tf_2		Q_{RSC}- $Q_{STATCOM}$	
1.	IF	HIGH-HIGH	THEN	MEDIUM-HIGH
2.	IF	HIGH-MEDIUM	THEN	MEDIUM-HIGH
3.	IF	HIGH_LOW	THEN	HIGH-HIGH
4.	IF	MEDIUM-HIGH	THEN	LOW-HIGH
5.	IF	MEDIUM-LOW	THEN	HIGH-HIGH
6.	IF	LOW-HIGH	THEN	LOW-LOW
7.	IF	LOW- MEDIUM	THEN	LOW-LOW

B. *The Reactive Power Control Technique*

Fig. 2 shows that, there are two states for switches S_1 and S_2.During normal condition, the switches S_1 and S_2 are closed in state 1. In this state the initial reactive power limits, denoted as $Q_{RSC}{}^0$ and $Q_{STATCOM}{}^0$ are maintained. During fault condition, the switches are transferred to state 2. The Fuzzy Logic Controller (FLC) acts suddenly and provides the optimal control values namely Q_{RSC}* and $Q_{STATCOM}$* to control the STATCOM which inturn compensates the required reactive power inorder to maintain the transient stability. The two sensitivity indices namely Voltage Severity Index (VSI) and Transient Power Severity Index (TPSI) are necessary to optimize the control parameters, through which Var compensation is achieved. The operation of FLC is based on fuzzy rules as shown in Table. I. The fuzzy subsets for the input variables, Tf_1 and Tf_2 is shown in *Fig. 3* .The fuzzy subsets for the output variables Q_{RSC}* and $Q_{STATCOM}$* are shown in *Fig. 4* and *Fig. 5* respectively.Table II and III shows the initiating values of parameters, m and σ, for the input and ouput fuzzy subsets .

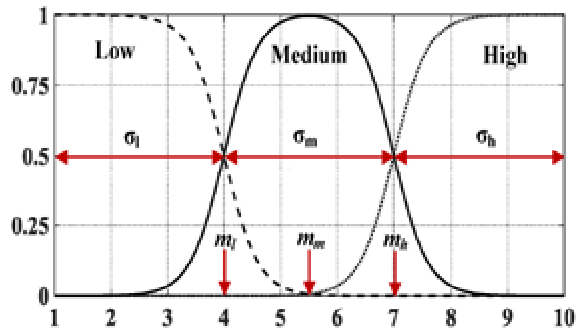

Fig. 3. Fuzzy input subsets of Tf_1 and Tf_2

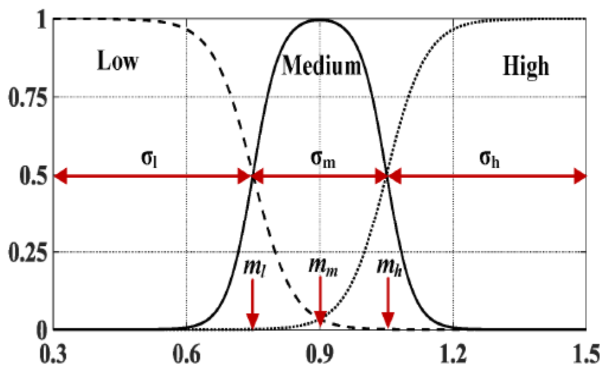

Fig. 4. Fuzzy output subsets of Q_{RSC}*

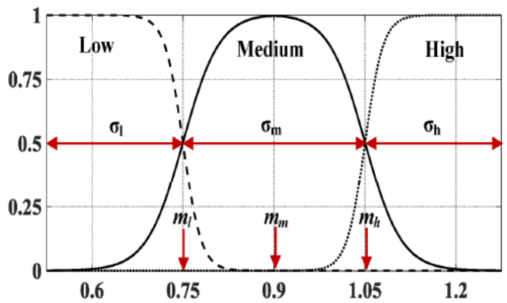

Fig. 5. Fuzzy output subsets of $Q_{STATCOM}$*

TABLE II. PARAMETERS TO INITIATE SIGMOIDAL MEMBERSHIP FOR INPUT, OUTPUT VARIABLES

Variables	Variables range	Low	Subset	Medium	Subset	High	Subset
		m_l	σ_l	m_m	σ_m	m_h	σ_h
$Tf_{1,2,3}$	[1, 2, …10]	4	3	5.5	3	7	3
Q_{RSC}*	(0.3 1.5)	0.75	0.45	0.9	0.3	1.05	0.45
$Q_{STATCOM}$*	(0.5 1.275)	0.75	0.225	0.9	0.3	1.05	0.225

TABLE III. PARAMETERS TO INITIATE SIGMOIDAL MEMBERSHIP FOR OUTPUT VARIABLES

Variables	Low	Subset	Medium	Subset	High	Subset
	m_l	σ_l	m_m	σ_m	m_h	σ_h
Q_{RSC}*	y_1	0.45	y_1+0.15	0.3	y_1+0.3	0.45
$Q_{STATCOM}$*	y_2	0.225	y_2+0.15	0.3	y_2+0.3	0.225

III. PROBLEM FORMULATION

A. . *Objective function*

The objective function is to minimize Voltage Severity Index (VSI) and Transient Power Severity Index (TPSI) given by equation 1 to 3. The objective function is subjected to both linear and non-linear constraints which are discussed in detail in the next section

$$VSI = \frac{\sum_{t=Ts}^{T} \Delta V_{PCC}{}^{t}}{T - T_s} \qquad (1)$$

$$\Delta V_{PCC}{}^{t} = \begin{cases} \dfrac{V_{PCC}{}^{t} - V_{PCC}{}^{0}}{V_{PCC}{}^{0}} & if \quad \dfrac{V_{PCC}{}^{t} - V_{PCC}{}^{0}}{V_{PCC}{}^{0}} \geq \alpha \\ 0 & otherwise \end{cases} \qquad (2)$$

$$TPSI = \frac{\sum_{i=1}^{N} \sum_{t=Tc}^{T} \left(\left| P_i^t - P_i^0 \right| \Big/ P_i^0 \right)}{N * (T - Tc)} \qquad (3)$$

where

$V_{PCC}{}^{0}$,	-	Voltage at PCC at time, T=0
$V_{PCC}{}^{t}$	-	Voltage at PCC at time, T= t
α	-	Voltage change outside the specified limits (±5%)
N	-	Number of buses
T_c	-	Fault clearing time
P_i^0	-	Real power during pre-fault condition
P_i^t	-	Real power at time, T=t

B. *Constarints*

The linear constraints are the real and reactive power balance given by equations 4 and 5.

$$P_G - P_L - P(V,\theta) = 0 \qquad (4)$$

$$Q_G - Q_L - Q(V,\theta) = 0 \qquad (5)$$

The non-linear constraints are denoted by set of equations in 6, which includes, apparent power limit (S), Voltage limit at various buses (V, $\angle\theta$), limits of real and reactive power of generators, reactive power limits of STATCOM

$$\left.\begin{array}{l} S(V,\theta) \le S_{\max} \\ V_{\min} \le V \le V_{\max} \\ P_G^{\min} \le P_G \le P_G^{\max} \quad Q_G^{\min} \le Q_G \le Q_G^{\max} \\ Q_{STAT}^{\min} \le Q_{STAT} \le Q_{STAT}^{\max} \end{array}\right\} \qquad (6)$$

The non-linear constraints, also consists of change in rotor angle $\Delta\delta$ at time =T should be within the tolerance limit β as given by equation 7.

$$[\max(\Delta\delta_{ij}^{\ T})] \le \beta \qquad (7)$$

By using the fuzzy logic controller, the control variables (QRSC and QSTATCOM) are adjusted with the help of the two parameters namely y1 and y2 is shown in equation 8

$$\left.\begin{array}{l} 0.3 \le Q_{RSC} \le 2MVar \\ 0.5 \le Q_{STAT} \le 2MVar \\ 0.7 \le y_1 \le 0.8,\ 0.7 \le y_2 \le 0.8 \end{array}\right\} \qquad (8)$$

To begin with the solutions for the control variables represented by, X = [Q_{RSC}, $Q_{STATCOM}$] and adjusting parameters of FLC, denoted as, Y=[y_1, y_2] are initiated using equation 9 to 11 respectively.

$$X_{new} = X_{iter} + (X_{\max} - X_{iter}).rand(0,1).\exp(-iter/\max iter) \quad (9)$$

$$X_{new} = X_{iter} + (X_{iter} - X_{\min}).rand(0,1).\exp(-iter/\max iter) \quad (10)$$

$$Y_{new} = Y_{iter} + rand(-0.5,0.5).\left[\left(Tf_1^{\ iter} + Tf_2^{\ iter}\right) \Big/ \left(Tf_1^{\ initial} + Tf_2^{\ initial}\right) \right] \quad (11)$$

The change in control variables are denoted as Δf1 and Δf2 are shown in equations 12 and 13 respectively which contributes for the final objective functions

$$\Delta f_1 = f_1^{\ norm}(Q_{RSC}^{\ new}, Q_{STAT}^{\ new}) - f_1^{\ norm}(Q_{RSC}^{\ iter}, Q_{STAT}^{\ iter}) \quad (12)$$

$$\Delta f_2 = f_2^{\ norm}(Q_{RSC}^{\ new}, Q_{STAT}^{\ new}) - f_2^{\ norm}(Q_{RSC}^{\ iter}, Q_{STAT}^{\ iter}) \quad (13)$$

IV. The Case Study USed For Simulation

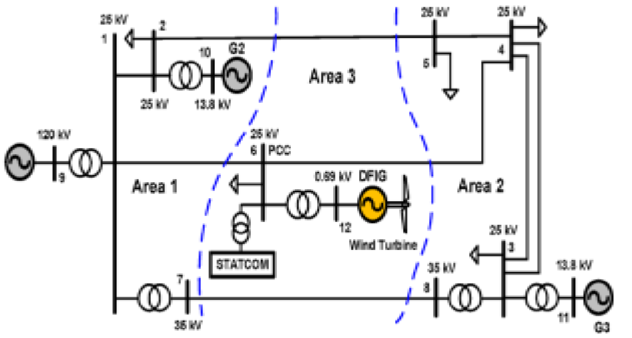

Fig. 6. Fuzzy based STATCOM controller for a 12 bus power system [15].

The power system considered for the study consists of 12 buses and 4 generators. The same simulated using MATLAB_SIMULINK with a wind turbine and a STATCOM controller, located at the Point of Common Coupling which is at bus 6 is shown in *Fig. 6*.The system is divided into three areas. The first area consists of generators G1 as well as G2. Generator G3 is in the load side which forms the second area. Doubly-Fed Induction Generator (DFIG) based wind turbine which under consideration for the study proposed, is rated at 2 MW and a 2 MVAr STATCOM, are associated with the third area. The speed of the rotor is 1.2 p.u. A transformer, rated at 0.69/25 kV is used to connect the DFIG to the grid. A three phase PWM converter is used to supply the rotor. A transformer rated at 13.8/25 kV is used to connect the STATCOM at the bus 6 which is the Point of Common Coupling. The system is simulated for the most sever symmetrical type of fault namely the three phase fault etween bus 1 and bus 6. The time of fault simulation is enoted as, T_s= 50 s and the time of fault clearing is represented as, Tc = 200 ms.

V. Results and Discussion

The graphical results of a 12 bus power system consist of a DFIG based wind turbine, equipped with a fuzzy logic based STATCOM controller, simulated with a three phase symmetrical fault are shown in Fig. 7 to Fig. 10. The rate of change of voltage magnitude at the point of common coupling during the fault is shown in Fig. 7. The transient voltage stability of the power system is optimally maintained, after clearing the fault through reactive power compensation offered by the STATCOM. It is clearly depicted in Fig. 8 that the low frequency real power oscillations are mitigated by the intelligent behavior of FLC based STATCOM controller during post fault conditions. The variations of control variables namely $Q_{STATCOM}$, and Q_{RSC}, with respect to time are during pre-fault and post-fault simulations are shown in Fig. 9 and Fig. 10 respectively.

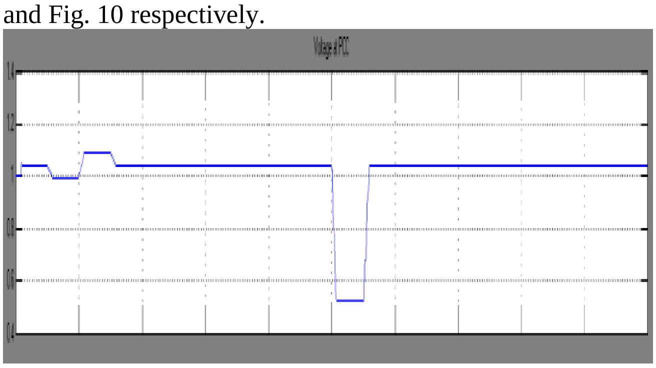

Fig. 7. MATLAB_SIMULINK ouput for voltage at PCC during 3 phase fault

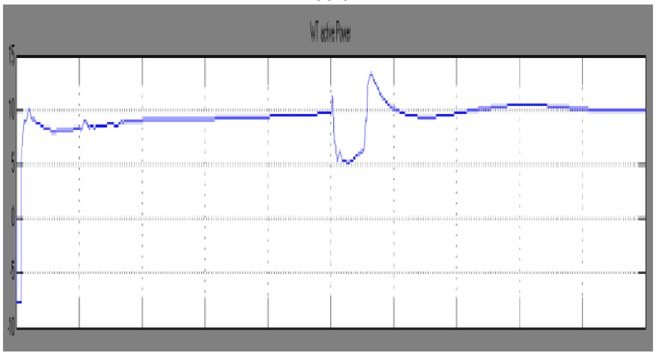

Fig. 8. Active power oscillations at the wind turbine during three phase fault

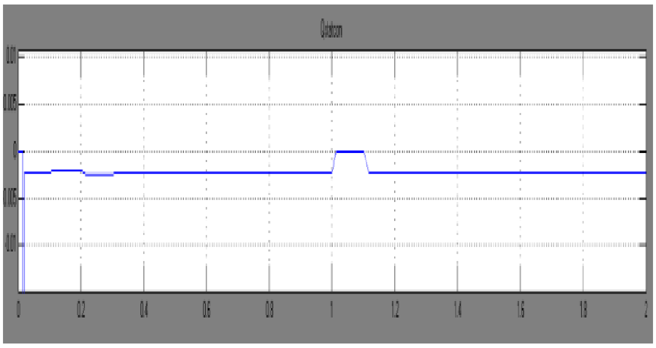

Fig. 9. MATLAB_SIMULINK ouput for $Q_{STATCOM}$ during three phase fault

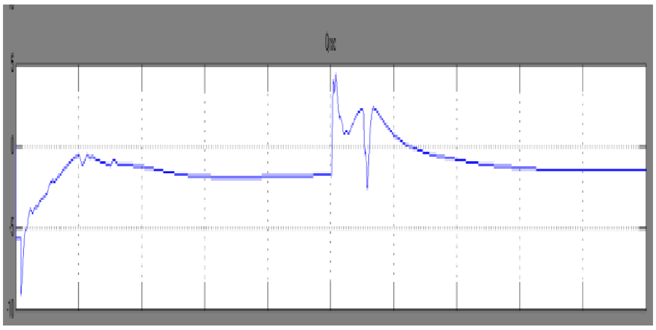

Fig. 10. MATLAB_SIMULINK ouput for Q_{RSC} during three phase fault

VI. Conclusion

This work presents a VAr compensation strategy of DFIG based wind turbine using STATCOM. A multi-objective problem will be formulated to improve the voltage stability by maintaining within its rated limits using VSI and to mitigate low frequency oscillations by using TPSI during three phase fault conditions. The solution for the proposed problem is optimized using Fuzzy Logic. In order to justify the proposed methodology it is modeled in a 12 bus power system [15] with a 2 MW DFIG using MATLAB- Simulink. The system is then tested by simulating a three phase fault. The graphical results of the case study are analyzed and presented. It is inferred from the results, that the fuzzy based reactive controller is effective in optimizing the power flow even during fault conditions.

In future, this work can be extended by using other types of FACTS controllers like SVC, TCSC, etc. The same work will also be implemented for higher bus power systems like IEEE 30, 57, 118, 300 buses. The same problem can also be studied by simulating various unsymmetrical faults, like, single line to ground (LG), double line to ground (LLG) and double line (LL) faults.

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